25. Faurie C, Khadra M. Technical competence in surgeons. *ANZ J Surg*. 2012;82:682-90.
26. Mahle WT, Lu M, Ohye RG, Gaynor JW, Goldberg CS, Sleeper LA, et al. A predictive model for neurodevelopmental outcome after the Norwood procedure. *Pediatr Cardiol*. 2013;34:327-33.
27. Gaynor JW, Gerdes M, Zackai EH, Bernbaum J, Wernovsky G, Clancy RR, et al. Apolipoprotein E genotype and neurodevelopmental sequelae of infant cardiac surgery. *J Thorac Cardiovasc Surg*. 2003;126:1736-45.
28. Goldberg CS, Bove EL, Devaney EJ, Mollen E, Schwartz E, Tindall S, et al. A randomized clinical trial of regional cerebral perfusion versus deep hypothermic circulatory arrest: outcomes for infants with functional single ventricle. *J Thorac Cardiovasc Surg*. 2007;133:880-7.
29. Limperopoulos C, Majnemer A, Shevell MI, Rohlicek C, Rosenblatt B, Tchervenkov C, Darwish HZ. Predictors of developmental disabilities after open heart surgery in young children with congenital heart defects. *J Pediatr*. 2002;141:51-8.
30. Tabbutt S, Ghanayem N, Ravishankar C, Sleeper LA, Cooper DS, Frank DU, et al. Risk factors for hospital morbidity and mortality after the Norwood procedure: a report from the Pediatric Heart Network Single Ventricle Reconstruction trial. *J Thorac Cardiovasc Surg*. 2012;144:882-95.
31. Ghanayem NS, Allen KR, Tabbutt S, Atz AM, Clabby ML, Cooper DS, et al. Interstage mortality after the Norwood procedure: results of the multicenter single ventricle reconstruction trial. *J Thorac Cardiovasc Surg*. 2012;144:896-906.
32. Pasqali SK, Ohye RG, Lu M, Kaltman J, Caldarone CA, Pizarro C, et al. Variation in perioperative care across centers for infants undergoing the Norwood procedure. *J Thorac Cardiovasc Surg*. 2012;144:915-21.

EDITORIAL COMMENTARY

CHD

Utility of the technical performance score for the Norwood operation … every score should know its limitations

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See related article on pages 2208-14.

The article by Nathan and colleagues[1] in this issue of the *Journal* provides additional data regarding the relationship of the technical performance score (TPS) to outcomes after the Norwood procedure among participants of the Single Ventricle Reconstruction Trial (SVR). Nathan and colleagues[1] conducted an ad hoc analysis of the SVR cohort of neonates undergoing the Norwood operation. By means of discharge echocardiography, available for 365 (65%) of the 549 patients in the study, a TPS category of optimal (72%), adequate (12%), or inadequate (17%), was assigned. The components of the TPS, which are weighted equally, include restriction at the atrial septum, residual aortic arch obstruction, and intervention on the chosen source of pulmonary blood flow. Neurodevelopmental outcome was assessed with the Bayley Scales of Infant Development (2nd edition). By means of multivariable regression, Nathan and colleagues[1] found that better TPS was associated with shorter time to initial extubation, improved transplant-free survival before discharge after the Norwood operation, shorter hospital stay, lower prevalence of unplanned interstage interventions, and better Bayley Scales Psychomotor Developmental Index (PDI) subscale scores at 14 months.

I applaud Nathan and colleagues[1] for extending their considerable work in this area and for using a multi-institutional cohort with prospectively collected data. The TPS has promise as the first objective tool that can both inform care and provide a platform for individual surgeon evaluation. There are important limitations to this study, however, that should temper Nathan and colleagues' conclusions[1] regarding the impact of the TPS on post-Norwood outcomes.

Factors that affect outcomes after the Norwood operation have been studied in detail with both prospective and retrospective data. It is clear from the majority of these studies that surgeon, institution, and patient factors play critical roles; however, the relative contributions of each component remain unknown and vary with different lesions and procedures. In analysis of arguably the best data collection available,[2-4] surgeon factors in the Norwood operation, including volume and experience (ostensibly a surrogate for technical performance), were identified as having minor influence on mortality relative to center or patient

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factors. In contradistinction, surgeon factors were paramount in their affect on outcomes after the arterial switch operation. It is not surprising, therefore, that a major limitation of the study of Nathan and colleagues[1] is the small portion of variation in Norwood outcomes explained by the TPS. The models had poor discrimination and explained at most 23% of the variability in outcomes among participating centers, with a meager increase in R^2 from 0.21 to 0.23 with the addition of the TPS. Another important limitation of the current TPS is the lack of association with midterm outcomes. Although the TPS was associated with selected short-term outcomes, the only midterm outcome identified was a single component of the neurodevelopmental index (PDI). Although I concede that optimum surgical results are essential, our specialty ought to investigate other factors that are potentially more important. Potential fruitful avenues could include further study of the concept of failure to rescue (which has great promise as an explanation for the mortality discrepancies among institutions), socioeconomic status, prenatal care, and institutional structure and process measures.

Calibration of the individual score components, which are currently weighted equally, raises another potential problem with the TPS. It is unlikely that issues with the source of pulmonary blood flow (especially if dealt with expeditiously) have the same implications as residual arch obstruction or restriction at the atrial septum for infants with single-ventricle physiology. It would seem plausible that an evaluative metric should include differential weighting.

The absence of a clear ordinal relationship between successive grades of the TPS and selected outcome measures further highlights this issue with calibration and is another limitation. For example, in most of the studied outcomes, the class 1 and class 2 scores were equivalent, and it was only class 3 scores that were separable. Perhaps the fact that the current TPS was consensus-based, rather than empirically derived, complicated the development of optimum cutoff points.

The analyses regarding neurodevelopmental outcome are extremely interesting and warrant further comment. First, it is not intuitive that operative factors per se would affect midterm neurodevelopment. A previous report from Tabbutt and colleagues[5] on 161 neonates undergoing the Norwood operation at a single center found no impact of surgical factors on neurodevelopmental outcome. Tabbutt and colleagues[5] concluded, "One must consider that perioperative management and perhaps post discharge interventional factors play more important roles in determining neurologic outcomes than do surgical strategies." This sentiment was echoed by Newburger and colleagues[6] in their report from the SVR trial, in which they concluded that patient factors and morbidity affected neurodevelopment among Norwood survivors more than did intraoperative management strategies. Second, the finding that the TPS was associated with the PDI subscale but not the Mental Developmental Index subscale at 14 months was surprising. Previous data from the SVR trial[6] found that similar variables (including complications after the Norwood operation and longer hospitalization, which presumably would be related to the TPS) were predictive of lower scores in each subscale. Improved sensitivity to motor as opposed to cognitive tasks among infants and a larger relative impairment in the PDI relative to the Mental Developmental Index are potential reasons for this discrepancy.

In summary, development of an objective metric to grade surgical performance is a critical *part* of ongoing efforts to improve outcomes for neonates undergoing the Norwood operation. Optimal results, however, will require enhancements of all components of perioperative care. Fortunately, the upcoming Pediatric Heart Network Trial will allow iterative refinement of the current TPS and provide additional clarity as to the importance of technical performance in this challenging patient population. Until then, the score, like the surgeons it evaluates, has its limitations.

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References

1. Nathan M, Sleeper LA, Ohye RG, Frommelt PC, Caldarone CA, Tweddell JS, et al. Technical performance score is associated with outcomes after the Norwood procedure. *J Thorac Cardiovasc Surg*. 2014; 148:2208-14.
2. Karamlou T, McCrindle BW, Blackstone EH, Cai S, Jonas RA, Bradley SM, et al. Lesion-specific outcomes in neonates undergoing congenital heart surgery are related predominantly to patient and management factor rather than institution or surgeon experience: a Congenital Heart Surgeons' Society Study. *J Thorac Cardiovasc Surg*. 2010;139:569-77.e1.
3. Hornik CP, He X, Jacobs JP, Li JS, Jaquiss RD, Jacobs ML, et al. Relative impact of surgeon and center volume on early mortality after the Norwood operation. *Ann Thorac Surg*. 2012;93:1992-7.
4. Karamlou T, Jacobs ML, Pasquali SK, He X, Hill K, O'Brien S, et al. Surgeon and center volume Influence on outcomes after arterial switch operation: analysis of the STS Congenital Heart Surgery Database. *Ann Thorac Surg*. 2014;98:904-11.
5. Tabbutt S, Nord AS, Jarvik GP, Bernbaum J, Wernovsky G, Gerdes M, et al. Neurodevelopmental outcomes after staged palliation for hypoplastic left heart syndrome. *Pediatrics*. 2008;121:476-83.
6. Newburger JW, Sleeper LA, Bellinger DC, Goldberg CS, Tabbutt S, Lu M, et al. Early developmental outcome in children with hypoplastic left heart syndrome and related anomalies: the Single Ventricle Reconstruction Trial. *Circulation*. 2012; 125:2081-91.